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RUSSELL FORK FAULT OF SOUTHWEST VIRGINIA¹

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INTRODUCTION

The nature of the northeastern termination of the great overthrust block of the earth's crust, bounded on three sides by the Pine Mountain fault, the Hunter Valley fault, and the Jacksboro cross fault of Tennessee, has long been an unsolved problem to students of Appalachian structural geology. Many geologists have noted the rather abrupt ending, near the breaks of Big Sandy River, of the imposing barrier of Pine Mountain and its replacement to the northeastward by the irregular ridges and valleys of the unbroken coal field, but the manner in which the great anticlinal fold and the resulting thrust fault died out has not until recently been satisfactorily solved.

In 1916 Hinds,² in his report on the Clintwood and Bucu quadrangles, called attention to a zone of disturbed rocks nearly at right angles to the general lines of disturbance in this region and extending partly across the trough of coal-measure rocks from Big A Mountain to Skegg Gap on Pine Mountain. Hinds attributed the disturbance in this zone to the same forces that produced the Hunter Valley fault on the southeast and the Pine Mountain fault on the northwest, but he failed to perceive its significance, for he thought it was limited to certain areas and did not extend entirely across the synclinal block.

In April, 1920, Mr. M. R. Campbell, in charge of geologic work in this coal field for the United States Geological Survey, called attention to the possibility of the belt of disturbed rocks mapped

¹ Published by permission of the Directors of the U.S. Geological Survey and the Virginia Geological Survey. The illustrations were prepared for the Virginia Geological Survey.

² Henry Hinds, "The Coal Resources of the Clintwood and Bucu Quadrangles, Virginia," *Virginia Geol. Survey Bull.* 12 (1916).

by Hinds being but part of a continuous fault or zone of faulting from the Hunter Valley fault at Big A Mountain to Skegg Gap in Pine Mountain, and the author was requested to examine the region as carefully as the limited time at his disposal would permit, in order to establish the character and extent of the movements that produced the disturbance. The result of his examination was the establishment of the presence of an overthrust fault entirely across the great crustal block, thus showing that it is bounded on all four sides by overthrust faults and that it has moved bodily to the northwest a distance of many miles. The results of his studies and their application to the mechanics of the problem of the overthrusting of this great mass of strata for at least six miles are here set forth.

The fault bounding the crustal block on the northeast, which, on account of its general agreement with the course of Russell Fork, is here called the Russell Fork fault, was mapped in connection with coal investigations carried on co-operatively by the Virginia Geological Survey and the federal Geological Survey. The areas mapped as undifferentiated buckled and faulted rocks by Hinds,¹ on the Clintwood and Bucu quadrangles, were subjected to careful study by the writer to determine whether or not there was a continuous break across the coal-measures trough from the vicinity of Big A Mountain to Skegg Gap, but in the two weeks spent on this study there was not time to cover much of the area lying on either side of this zone and the structure contour maps of the report by Hinds furnished many data in compiling the sections shown below and in deducing the amount of displacement.

The writer is indebted to Mr. M. R. Campbell for many helpful suggestions and much assistance in the course of the study.

Hinds,² in his report on the coal resources of the Clintwood and Bucu quadrangles, describes the structure of the northeastern end of the Middlesboro syncline in considerable detail. His studies here and farther northeast in Buchanan County³ have shown that

¹ *Op. cit.*

² *Op. cit.*

³ Henry Hinds, "Geology and Coal Resources of Buchanan County, Virginia," *Virginia Geol. Survey Bull.* 18 (1918).

the great overthrust of Pine Mountain suddenly becomes very much less severe at Skegg Gap, and from there northeastward the structure is essentially a low anticline broken by a minor overthrust which decreases rapidly in extent of thrust and comes to an end a few miles into Buchanan County. He considered that the principal Pine Mountain overthrust was cut off at the northeast end by the Skegg Gap fault which he mapped as far as Russell Fork. Between this point and Big A Mountain he has mapped a number of narrow areas of faulted and buckled rocks which he describes in some detail and in explanation of which he postulates lateral shearing with the southwest side moving northward with some overthrusting and buckling against the northeast side. He states that succeeding this movement there was normal faulting along this line in which the southwest side was downthrown. His evidence for this belief is not clear, and his several areas of disturbed rocks are separated by areas in which he found no evidence of movement.

DESCRIPTION OF THE CUMBERLAND BLOCK¹

The structure of the area concerned in this paper has been described in considerable detail at many points by previous writers.² It is not the writer's purpose to give here a thorough description of the structure or topography but rather to point out briefly their alien features.

The "remarkable quadrilateral block" whose southwestern extremity was first recognized by Safford and described in detail by Keith extends from the valley of Cove Creek in Campbell County, northeastern Tennessee, northeastward for one hundred and twenty-five miles to the valley of Russell Fork of Big Sandy River in Dickinson and Buchanan counties, Virginia. It is surprisingly uniform in width, averaging about twenty-five miles, is bounded on the northwest by the Pine Mountain fault and on the southeast by the Hunter Valley fault and the closely associated Wallen Valley fault, which is developed only from near Big Stone

¹ This name is here applied for the first time.

² J. M. Safford, *Geology of Tennessee* (1869); M. R. Campbell, *Geologic Folios 12 and 59*, Arthur Keith, *Geologic Folios 33 and 75*, G. H. Ashley and L. C. Glenn, *Prof. Paper 49*, all of the *U.S. Geol. Survey*.

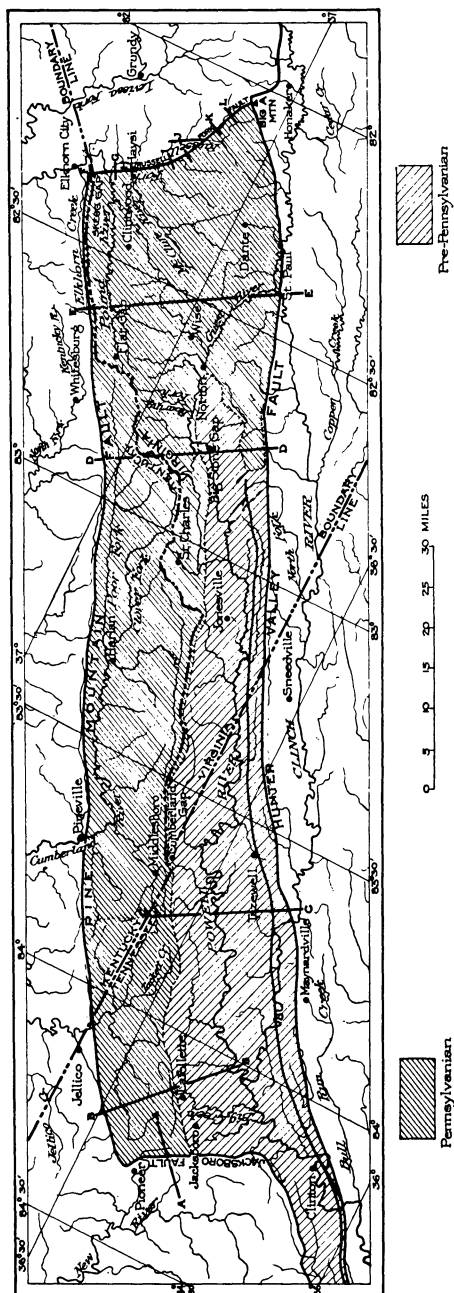


FIG. 1.—Areal map of the Cumberland block showing its location in the states of Virginia, Kentucky, and Tennessee and locations of the structure sections of Figures 3 and 4.

Gap southwestward. The southwest end is terminated by the Jacksboro cross fault and the northeast end by the Russell Fork cross fault to be described below in more detail. The general relations of these boundary faults may be more clearly seen by reference to the map and diagram, Figures 1 and 2, and to the structure sections, Figures 3 and 4.

From Norton, Virginia, northeastward, coal-measure rocks are exposed at the surface throughout the entire width of the block; but from Norton southwestward the block may be divided into two parts, that part lying northwest of Stone and Cumberland mountains being synclinal in structure and composed of coal-measure rocks, whereas that part lying southeast of these mountains is anticlinal in structure and composed of rocks of very much greater age. The syncline, which is now generally known as the

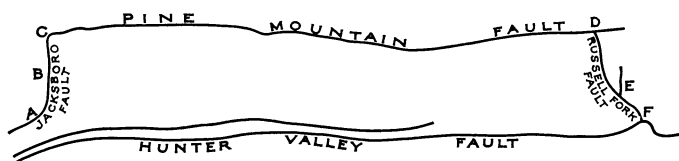


FIG. 2.—Outline diagram of Cumberland block showing the bounding faults

Middlesboro syncline, is a broad, flat-bottomed trough at the northeast end of the block, but farther west in the vicinity of Dante an arch appears which develops rapidly westward into the Powell Valley anticline that constitutes the southern part of the block. Both the Middlesboro syncline and the Powell Valley anticline are characterized by steep dips on the northwest limbs and gentle dips on the southeast limbs, as shown in the sections. The erosion by Powell River and its tributaries of the rising crown of the Powell Valley anticline accounts for the exposures of pre-Carboniferous rocks in the southern portion of the block and the narrowing of the coal-measure portion on the north. The general relation of these different structural units and their expression in the areal relationships of the Pennsylvanian and pre-Pennsylvanian rocks may be seen by reference to Figure 1.

The topography of the block is intimately related to the structure. Pine Mountain throughout its entire length is a conspicuous

barrier especially on its northwest face, where at many points it rises in less than a mile one thousand to two thousand feet above the streams which parallel it. For nearly ninety miles no stream crosses it and in the entire distance of one hundred and twenty-five miles not over half a dozen roads afford passage from one side to the other. Its crest is the resistant conglomerate of the Lee formation, which marks the edge of the overthrust block. Cumberland Mountain and Stone Mountain are composed of the same formation, which is steeply upturned in that part of the fold common to the syncline and anticline mentioned above. Black Mountain and parts of Sandy Ridge are residual mountains left in the dissection of the nearly horizontal coal measures. Big A Mountain, according to Hinds,¹ is composed of resistant sandstones of the Rockwood formation, overthrust on the coal measures.

The surface features of that portion of the block within the coal field are those of a maturely dissected plateau with sharp-crested ridges and V-shaped valleys, for the most part without valley flats. The surface of the pre-Carboniferous portion is rolling, with sink holes in the limestone portion and some, though not at this particular point very striking, allineation of ridges and valleys with the northeast-southwest trend of the Appalachian structure. The surface configuration of the area and the control of topography by the great structural features is admirably shown on the contour maps of the United States Geological Survey, to which the reader is referred for further detail.

THE RUSSELL FORK FAULT

The Russell Fork fault differs from the faults which bound the Cumberland block on the other three sides in that it is not a low-angle overthrust and that in it the greatest displacement is in a horizontal direction with comparatively little vertical movement. Its trace² is closely followed except at a few places by Russell

¹ Henry Hinds, "The Geology and Coal Resources of Buchanan County, Virginia," *Virginia Geol. Survey Bull.* 18 (1918), pp. 58-59.

² "Trace" of a fault is here used in its mathematical sense of the line of intersection of one surface with another, i.e., the intersection of the fault plane with the surface of the earth.

Fork of Big Sandy River, and even at those places it is marked by the allineation of minor drainage lines or surface features which would not otherwise be easily explained.

Erosion of crushed and weakened rocks along the fault trace has produced the low saddle at Skegg Gap and the saddle in the point of the spur west of Russell Fork and one mile north of B.M. 1221¹ on the Clintwood quadrangle.

From a point one-half mile upstream from B.M. 1282 to B.M. 1221 Russell Fork flows in a course somewhat farther northeastward than in adjacent parts of its course up and down stream. In the high land which lies southwest of this part of the river and northwest of the village of Haysi are cut two short cleftlike hollows which are closely aligned with the fault trace as located to the north and south, and have without doubt been determined by the presence of the weaker rock in the zone of deformation adjacent to the fault. One of these hollows enters the river valley just at the railroad bridge east of B.M. 1221 and the other extends from near Haysi south and just to the west of B.M. 1380. These hollows are somewhat straighter and narrower than most of the ravines of similar size which erosion has cut in the rocks of this region, but their most distinctive characteristic is their location where they cut off in part the narrow strip of high land between them and the river. Taken together and with the other topographic features which show alignment, they are very significant, and their locations are not to be explained as accidental.

Between McClure River and Russell Fork, at the close approach before they join, a low saddle in the spur owes its position to the weakness of the rocks along the fault line. The very straight course of Fryingpan Creek from elevation 1,311 feet to its mouth is determined by the fault, and it is interesting to note that this creek has a very slight fall in this part of its course and its bed is graded for the entire distance with ripple-marked sand. Russell Fork leaves the fault trace at a number of points and because of its cutting across the undisturbed and more resistant rocks at

¹ The area crossed by Russell Fork fault is shown in detail on the Regina, Ky., and the Clintwood and Bucu, Va., sheets of the *Topographic Atlas of the United States*. Frequent reference is made to points on these maps in locating the features described.

these points is not so perfectly graded. But the weakness of the disturbed rocks close to the fault has apparently enabled Fryingpan Creek, though a comparatively small stream, to grade its lower course to the temporary base as determined by the rocks over which Russell Fork flows.

The main line of the fault passes somewhat to the north of Abners Gap; from elevation 1,424 feet southeast to the mouth of Carroll Presley Branch it follows Russell Fork for most of the distance, and thence southeast to the point where it is truncated by the main overthrust fault; in the north face of Big A Mountain its trace lies somewhat to the north of the channel of Russell Fork.

A branch leaves the main fault at elevation 1,424 feet, and extends northwestward along the course of Russell Fork to a point in Little Pawpaw Valley about a mile north of Cannady Post Office, and is here named the Little Pawpaw fault.

Along most of its course the rocks northeast of the fault are horizontal or nearly so and undisturbed. The fault plane, or, better perhaps, the planes of movement, for the most part dip at high angles, 75° to 90° to the southwest. That there has been intense compression is shown by the mashed condition of the shale and jointed condition of sandstone on the southwest side of the fault. At numerous exposures in the zone of faulting, slickensides indicate considerable vertical movement which has resulted in lifting the beds on the southwest above those on the northeast, displacing the coal beds by from 50 to 200 feet. Because of the shearing which has brought anticlines into contact with synclines and vice versa, it is difficult to determine the true amount of differential vertical movement, but the essential point is that the vertical movement is slight and that the hanging wall has moved up as a result of thrust. At many points there are planes other than those which bear the vertical slickensides, a series of horizontal slickensides trending closely in the direction of the fault, and usually these surfaces are rubbed and planed much smoother and more nearly plane than the others, indicating, it seems to the writer, that these surfaces are the result of more extensive movement along the fault line than the other planes along which

a slighter movement has taken place, to accommodate the thrust in a direction lateral to the main Russell Fork fault line (Figs. 5 and 6.)

At a few points, notably at Skegg Gap (Fig. 7), the slickensides and planes of movement within the zone of faulting indicate a combination of the main southeast-to-northwest thrust with the side or southwest-to-northeast thrust, making the direction of movement a resultant of the two. The slickensided surface here shows the result of pronounced movement and the white quartz pebbles which are so numerous in the Lee formation are planed off flush

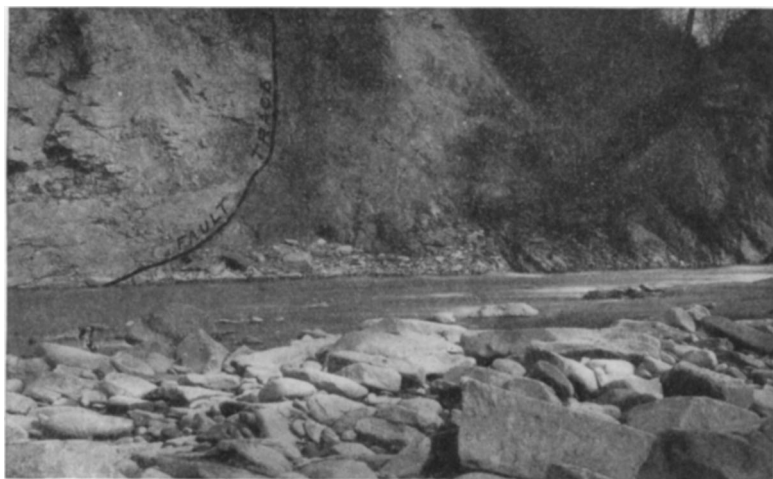


FIG. 5.—View of river bank looking southeast near B.M. 1221. Massive and undeformed sandstone on left of fault trace with deformed shale at right. Strong horizontal slickensides are formed on the face of the sandstone at this place.

with the matrix. It is important to mention that a short distance northwest of Abners Gap the writer saw the most abundant evidence of thrust in the mashing and crushing of shale in a fine exposure and that here the slickensides indicate movement at an angle of 45° to the horizontal in a due north direction. At this point the fault trace is more nearly athwart the main direction of thrust, and here, if anywhere, would be expected evidence of strong overthrust.

In the Little Pawpaw fault there was seen little indication of shearing but abundant evidence of compression and slight overthrusting.

MECHANICS

The history of the deformation (Fig. 8) is conceived to be as follows:

The rocks of the Cumberland block were subjected to strong lateral compression applied from the southeast. The thicker sedimentary rocks west of *A* (Fig. 2, p. 355) seem not to have yielded as did those to the east, and acted as a buttress against which the rocks to the east were deformed. The compressional stress was much more intense at the Tennessee end of the block and the first result of the stress was the folding of the Powell Valley anticline and of the lateral anticline which later broke and formed the Jacksboro cross fault. Between *A* and *B* Keith¹ found evidence of this now broken anticline which was the result of deformation of the rocks of the Cumberland block against the more competent buttress on the west.

After the Powell Valley anticline had been in large measure formed and the Jacksboro cross anticline had probably reached its full development, the stresses were then transmitted across the block, and yielding farther northwest resulted in the folding of the rocks into the Pine Mountain anticline. It is probable that by this time overthrusting and shearing to the northwest had commenced at the southern end of the Jacksboro cross anticline, for the movement of the rocks of the Powell Valley anticline northward differentially with respect to the nearly undisturbed rocks on the west had already been very considerable. With the continued crumpling of the Pine Mountain anticline, the Jacksboro cross fault developed progressively toward the northwest, and, when it reached the then position of the corner *C* of the block, initiated the great Pine Mountain fault.

There had by this time been considerable skewing of the entire block which was pivoted at or near its north corner, with the result that the corner of the block at *A* had been thrust more extensively on the rocks to the west than had the corner at *C*. The overthrust to the west in the Jacksboro cross fault is, however, believed to be only the smaller movement incidental to the skewing of the block, while the main movement in this fault was

¹ Arthur Keith, *U.S. Geol. Survey Geol. Atlas, Briceville Folio No. 33* (1896).

the shearing by which the block to the east moved several miles to the northwest. The writer does not believe that there was in the original stress any distinct southwesterly component, but



FIG. 6.—Slickensided shale near mouth of Lick Creek south of Birchleaf

considers the Jacksboro thrust to be solely the result of the twisting of the block.

The Pine Mountain fault is compound at *C*, consisting of four distinct overthrusts, but becomes more simple northeastward. The faulting which commenced at the southwest developed progressively toward *D* as the stress continued, but naturally the

total displacement was less at *D* than at *C*. It seems likely that there was some slight displacement beyond Skegg Gap and into Dickinson County along the Pine Mountain fault before it was intersected by the Russell Fork cross fault.

In following chronologically the development of the Jacksboro-Pine Mountain line of faulting the Russell Fork cross fault was temporarily omitted. The history of its development is correlated with the events described above, as follows:

Only after there had been considerable development of the Pine Mountain anticline at *C*, and some shearing along the Jacksboro cross fault, was the skewing of the Cumberland block felt at the northeast end. Its first expression was the development of a tension or normal fault starting at *F* (Fig. 2) and extending toward *E* with continued twisting of the block.

The presence of the Little Pawpaw fault, which appears to be primarily the result of such tension incident to twisting, leads the writer to believe that the point, or, perhaps more correctly, the area of pivoting, was somewhat to the north of *E*. On the other hand, evidence of somewhat more pronounced compression along the fault from *D*, part of the distance toward *E*, seems to indicate that compression was even at first dominant in that part of the line. It seems therefore probable that the region of pivoting is located between *D* and *E* but somewhat nearer the latter.

After the extension of the Pine Mountain fault beyond Skegg Gap and the extension of the Russell Fork cross fault beyond *E* as a normal fault, the accumulation at the northeast end of the block of the northwestward-trending stresses, which had long been operative at the Tennessee end of the block, reached the critical point, and the northeast end was broken loose along the line largely determined by the pre-existing normal fault. The line of this break intersected the Pine Mountain fault at Skegg Gap, stopped farther movement in that fault east of that line, and permitted the Cumberland block to be thrust not over two miles northwestward at this end. Since the Russell Fork fault line forms an angle of over 90° with the line of the Pine Mountain overthrust, the overthrusting of the east end of the block brought about compression along the whole extent of the Russell Fork

fault, reversing the condition of tension which produced the normal fault, and producing overthrusting and considerable crumpling of the shale and crushing and jointing of the sandstone adjacent to the fault plane. The net amount of overthrust is very slight, probably at no point reaching 500 feet, and the rocks on the southwest side of the fault are nowhere over 250 feet above those on the northeast. The shearing loose of the northeast end of the block, its overthrust along the already established Pine Mountain



FIG. 7.—View of Skegg Gap looking north along fault line. At this point the resistant basal conglomerate of the Lee on the overridden side (right) is adjacent to the weak Pennington rocks of the overthrust side (left).

fault, and the compression and slight thrusting along the Russell Fork cross fault were the closing events in the history of the Cumberland block as a unit.

There are many especial features which are particularly in accord with this interpretation of the movement of the Cumberland block as a progressive skew with final release of the east end. The skewing of the southwest end of the block first with the Skegg Gap corner remaining longest in place explains admirably the otherwise anomalous facts of rather strong overthrust in the Jacksboro fault, the trace of which is nearly at right angles to

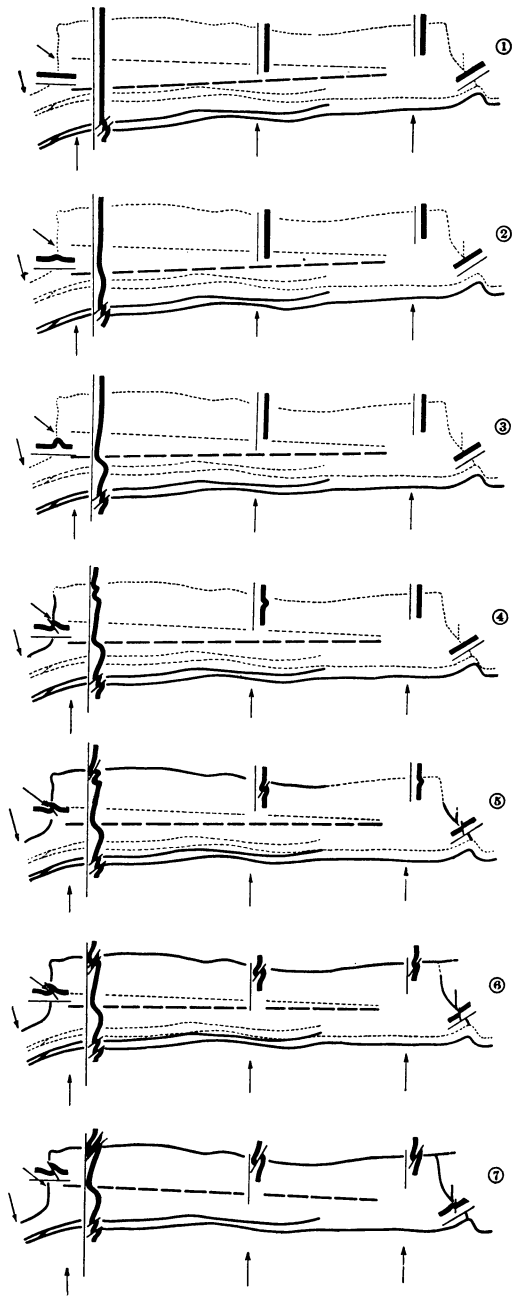


FIG. 8

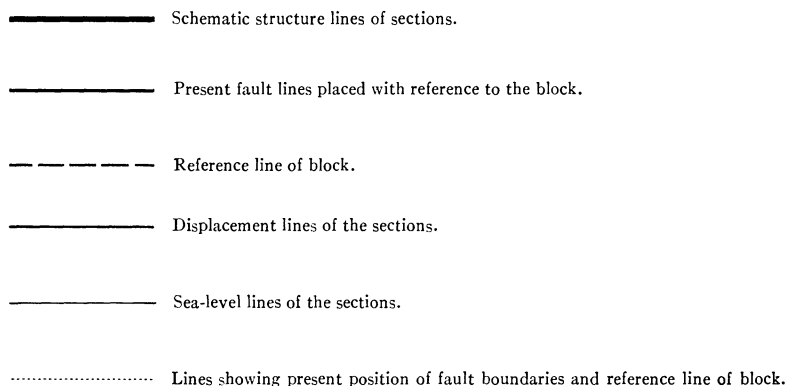


FIG. 8.—Serial diagram showing history of the deformation and displacement of the Cumberland block as interpreted by the writer. In sketch No. 7 of the series is shown the present condition in outline. The heaviest lines show the structure in the sections schematically. The lightest lines are the “sea-level” lines of the sections and the fault lines of the sections still referring to sketch 7 of the series above. The solid lines of medium weight are the present traces of the various faults. The medium-weight dotted line is an arbitrary axis line the position of which is the same with reference to the block in each sketch of the series.

In sketch 1 of the foregoing series the present fault traces are shown by the light dotted lines of the background and the present position of the axis line by the light and straight dotted line. The then position of the fault traces and of the axis line of the block is shown in sketch 1 by the medium-weight solid and dotted lines respectively. The light “sea-level” lines and fault lines of the sections and the very heavy lines of the schematic sections are the same as in sketch 7. The arrows which point upward in the sketches indicate the direction of the main thrust; the arrows pointing down and to the right at the left-hand end of each sketch indicate the resisting stress of the buttress southwest of Jacksboro as described in the text.

The first sketch assumes the prior formation of the Hunter Valley. The second shows some slight buckling of the southwest end of the block. The third shows more intense buckling here. The fourth shows more intense buckling and extension of the folding eastward along the line of the Pine Mountain fault. In No. 4 also is shown the beginning of the Jacksboro overthrust fault. In No. 5 this fault has extended far around the north side of the block and the Russell Fork fault has been initiated as a normal fault. Sketch 6 shows further extension of the faulting and only a small corner of the block near the northeast corner remains attached. In sketch 7 this small attachment is broken and the block has been thrust into its present position. The relative movement of the block at different stages has been shown by the gradual migration of the heavy dashed axial line toward its final position as shown by the light dotted axial line of each sketch.

the trace of the Pine Mountain fault and of only slight overthrust and more restricted compression in the Russell Fork fault with its trace at a much greater angle with the main overthrust.

The stronger development of the Powell Valley anticline and the presence of the Wallen Valley fault only at the southwest are also strongly in accord with this suggested interpretation.

The greater intensity of stress implied by the compound character of the Pine Mountain overthrust at C (Fig. 2) and the probable development of the Powell Valley anticline before the rocks of the block were competent to transmit the stresses to the Pine Mountain fold which later broke in a fault, point strongly to the initiation of the faulting at the south end of the Jacksboro cross fault to allow the necessary shortening of the strata on the northeast side of that fault. The four faults as interpreted by Keith, and corroborated by the displacement of the north limb of Powell Valley anticline in the Briceville quadrangle, give clear evidence of a movement of at least ten miles to the northwest. At Skegg Gap the evidence does not indicate over two miles of overthrust at the most.

In the course of his meditation on this study the writer has made very briefly a few computations, based on extremely general and only very approximate assumptions, which are given below. Their value is solely to indicate orders of magnitude, and it is hoped that they may serve, as they did in the case of the writer, to visualize the immensity of forces involved.

FORCE TO SHEAR AND FORCE TO THRUST

ASSUMPTIONS

Block 125 miles \times 25 miles \times $\frac{1}{2}$ mile

Density 170 lbs. per cubic foot

Coefficient of friction, mean between rough and smooth granite, 0.60

Shearing strength 200 pounds per square inch

Average extent of overthrust, 6 miles

RESULTS

Force to shear block loose over entire area = 25×10^{14} pounds

Force to move block against friction on horizontal plane = 23×10^{15} pounds

Work done in moving block 6 miles at angle of 5 degrees = 85×10^{19} foot pounds

Equivalent to 420,000 horse-power working for 100,000 years

Estimated coal in block = 50×10^9 tons

Burning of this coal would produce power enough to move the block 2.2 feet, assuming the usual engine efficiency. It has actually moved an average of at least six miles.

It is especially interesting to note that the force required to shear the block loose over the whole area is only about one-tenth of that required to produce motion against the resistance of friction. Since both forces are proportional to area and only one—that of motion against friction—proportional to thickness, we find that for a block of any area and of a thickness of 287 feet, according to the conditions assumed, the shearing force is just equaled by the force to overcome friction, and as thickness is greater than this amount the latter force is greater in proportion. It is evident, then, that in the case of most overthrust faults the motion of the rock involved against the resistance of friction is more impressive than the production of the break which separated it.